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Potential wind power generation in South Egypt

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ABSTRACT

Egypt is one of the developing countries. The production of electricity in Egypt is basically on petroleum, natural gas, hydro-power and wind energy. The objective of this work to prove the availability of sufficient wind potential in the wide area of deep south Egypt for the operation of wind turbines there. Nevertheless, it gives in general an approximate profile which is useful to the wind parks design for this area. The data used in the calculation are published and analyzed for the first time. The diagrams of the measured wind data for three meteorological stations over a period of two years (wind speed, frequency, direction), wind shear coefficient, the mean monthly and annual wind speed profile for every location are presented. Monthly Weibull parameters, standard deviation and coefficient of variation have been statistically discussed. A comparison of the rose diagrams shows that the wind speed is more persistent and blow over this region of Egypt in two main sectors N and NNW with long duration of frequencies from 67% to 87% over the year with an average wind speed in the range 6.8–7.9 m/s at the three stations. Evaluation of monthly wind energy density at 10 m height by two different methods was carried out. And the final diagram for every site shows no significant difference between them. The annual natural wind energies at 70 m A.G.L. lie between 333 and 377 W/m^2 for Dakhla South and Kharga stations, respectively, which is similar to the inland wind potential of Vindeby (Denmark) and some European countries. These results indicate that Kharga and Dakhla South locations are new explored sites for future wind power generation projects.

Contents

1. Introduction

Fossil fuel is getting more and more expensive every year, and is not readily available in some remote locations. Since earliest recorded history, man has been harnessing the energy of the wind. There is evidence that energy was used to propel boats along the Nile River in Egypt by the Egyptians 5000 years ago. Today, wind power can be harnessed to provide some or all of the power for many useful tasks such as generating electricity, pumping water and heating a house or barn. Egyptian developing plans during the last 30 years have necessitated an increase in energy consumption. About 85% of Egypt's electricity is produced in power plants predominantly operated with natural gas, while the remaining 15% are produced through water and wind energy. Where Egypt does not possess enough fossil reserves at deep south country, possesses only in this region large resource for electricity generation hydropower (High Dam Aswan).

The New & Renewable Energy Authority (NREA) was established in 1986 at Cairo, Egypt to act as the national focal point for

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expanding efforts to develop and introduce renewable energy technologies to Egypt on a commercial scale together with the implementation of related energy conservation. The national wind energy resources assessment was one of initial goals of the NREA, early research in wind characteristics included the development and application of techniques and direction of wind resources over selected areas, within the Renewable Energy Field Test Program (REFT), the specific Northwest Laboratory (USA) used these resource assessment techniques in preparing the annual average wind resources on a regional level in a real distribution analyzed form. They provide an input so that a wind data screening procedure is currently being developed to update the national map of annual average wind resource with higher certainty ratings in land surface a real distribution form. Also, the wind atlas for Egypt, produced jointly by Egyptian and Danish scientists, were presented to the delegation.

Egypt has two coastal areas that show significant promise for wind energy exploitation; the north coast on the Mediterranean Sea and the east coast on the Red Sea. The wind energy is utilized along the coast of Mediterranean Sea in Egypt on few occasions, while from national programs for wind energy utilization in Egypt, at the Red Sea coast, the master plan calls for 600 MW which are expected to be achieved by the year 2005. Where the wind park Zafarana on the Red Sea coast is being developed over a number of years as a German–Danish–Egyptian joint-venture: its installed capacity will reach 430 MW by the end of year 2007. Germany supports research and training in renewables, not only in Egypt but equally in the region. EURO 6 million were allocated under Financial Cooperation (FC) via KfW Entwicklungsbank for a Regional Research and Training Center for the MENA-region. This is an important step for improving one of the major bottlenecks for building a local renewable industry: the lack of qualified staff on all levels. Hence, Egyptian Ministry of Electricity and Energy has development strategy from the year 2007: the target of having 20% of electricity produced by renewable energies by 2020 [1–11].

Until now, there have been very little articles of wind power about deep south Egypt [12–17]. So, the study of territorial wind distribution is useful from two points of view. First, no systematic investigation on this subject was carried out until recently in deep south Egypt to characterize the territorial wind distribution, as it has been for most coast of Red Sea in Egypt, and without careful analysis it is not possible to assess the resources and the local real suitability of wind machines. Besides, concerning the energy exploitation, there are some useful applications that do not need high wind intensities, like water pumping for irrigation and drinking water from depths that are mostly not very deep.

This paper shows the results of a preliminary analysis on the wind resource in south Egypt. The goal of this research is:

(1) Generate a useful set of numerical values of wind energy which will serve as a frame of reference for calculation of potential energy for the engineering specifications of various conversion systems.
(2) Prepare wind energy profile of this area in deep south Egypt.
(3) Determine whether or not this wind potential is sufficient for the operation of a wind turbine.

2. Instrumentation and measurements

The wind data of three stations at deep south Egypt are chosen to investigate the wind power potentials in this area. Fortunately, a network of meteorological stations has been established in south Egypt recently supplied by the Egyptian Meteorological Authority and New & Renewable Energy Authority in Cairo, Egypt. The analysis was carried out on the basis of the wind data collected at three sites namely: Kharga, Dakhla South and Abu Simbel. These wind-measurements stations are shown in Fig. 1. Winds were measured at 24.5 m elevation over ground, measurements are made hourly during the day. About two years (2004–2005) were examined. They are sufficient for a preliminary analysis, which is intended to follow by an accurate and long-term measurement campaign in the more promising areas. Where the data presented herein are in good agreement, but still needed extensive data collection. Also, the data presented at this stage can serve as a good indicator for researchers and policy makers in planning the utilization of wind energy in deep south Egypt. The need for wind information is essential in the design and study of wind energy conversion devices. Other uses of such information include agricultural studies, meteorological forecasting, environment and energy conservation. The detailed locations of the three sites are listed in Table 1.

2.1. Kharga station

The Kharga mast is situated just west of the Asyut-Kharga road, in a wide (more than 10 km) valley about 35 km north of the oasis and town of Kharga. The site is close to the HT power line connecting Kharga to the national grid. The nearby surroundings consist of a flat and fairly homogeneous desert surface. The surface is a mixture of sand, gravel and stones with a roughness length of about 1 cm or less. There are no sheltering obstacles close to the mast.

2.2. Dakhla South station

The Dakhla South mast is situated in Western Desert, just west of the Dakhla-Shark El-Quinat road, approximately 106 km south of the town of Dakhla along this road. The station is equipped with a satellite transmitter, which makes is able to provide online data. There is no sheltering transmitter, which makes is able to provide online data. There are no sheltering obstacles close to the mast. The surface consists mostly of very smooth uniform sand with a roughness length of less than 0.001 m.

2.3. Abu Simbel station

The Abu Simbel mast is situated about 8 km NNW of the airport of Abu Simbel. Lake Nasser is located to the east of the site, but at distance of about 7–10 km or more. The terrain consists mostly of a flat uniform sandy desert, but with some rocky outcrops or 'hills' to the east and south-some of these are several tens of meters high. To the north and west the terrain is very open and there are no hills or other obstacles.

3. Wind data adjustment and description

The wind speed distribution predominantly determines the performance of wind power systems. Once the wind speed distribution is known, the wind power potential and, hence, the economic viability could be easily obtained. Also, a well-known feature of the annual wind speed at a location is useful as an initial indicator of the value of the wind resource. Desert regions could provide space for large-scale utilization of wind energy, provided they are favoured by a healthy wind climate and situated not too fare from places where power is very in demand [18].

The data available is for two years on an hourly basis starting from January 2004 and ending in December 2005. This is the minimum data duration that is required for any wind power project in Egypt. Of course, it is preferable to have wind data for 5 years, if the case is applicable. In this section, a description will be given of the platforms used in the analysis. The problems in this process will be discussed and analysis and the availability of the wind

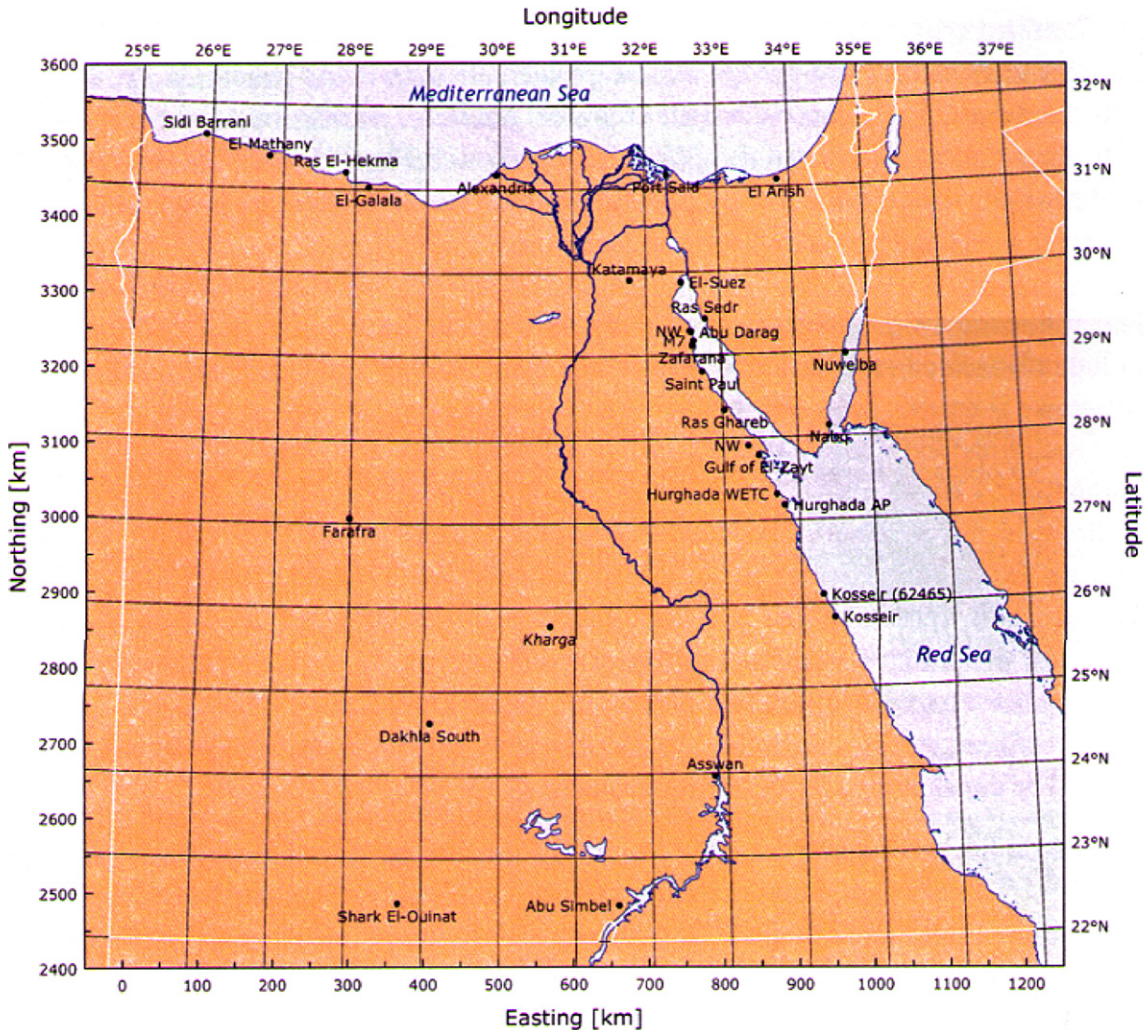

Fig. 1. shows the location of meteorological stations in South Egypt.

speed data will be presented. Table 1 lists the three stations mentioned in above, with their latitude, longitude, elevation, estimated wind share coefficient, wind direction and the annual mean velocity (2004–2005). Where, the prevailing wind direction was north (360°) over the year at the three stations.

The first step in the process after the initial measurement in m/s is the conversion of the wind speed to the standard height. The standard height according to the World Meteorological Organization, is 10 m above the ground level [19]. At the beginning the wind shear coefficient is determined by the wind speed data obtained with anemometer height 24.5 m at the three locations under study with the simple equation stated in many studies [20–22], and found to be in the range of 0.22–0.24 (see Table 1).

The next step is the conversion the wind speed from 24.5 m to 10 m height for all sites and the results were presented at Table 2. Where the measured values of monthly wind speeds are listed in the second row of this table, and the estimated values at 10 m height have been prepared in the first row. Additionally, it is further observed that the profile of the monthly mean values of the wind speed for the successive months of the 2 years for all regions are illustrated in Fig. 2.

The velocity duration curves for selected sites have shown that:

(1) The range of wind velocities for those stations against the number of months in the year for which the velocity is equal to or greater than a specific value.
(2) In Kharga station: it has a velocity of 5.4 m/s and higher at 10 m height for almost eight months in the year compared with Dakhla South station which has wind speeds of 5 m/s and higher for almost seven months. However, at Abu Simbel station has only a velocity of 5.2 m/s for two months during the whole year.

Table 1
Geographical data of the selected sites and wind characteristics.

Station	Latitude (°)	Longitude (°)	Altitude (m)	Anemometer height (m)	Wind shear coefficient (α)	Annual mean wind speed (m/s)		Wind direction
						At 10 m	At 24.5 m	
Kharga	30° 39	25° 46	102	24.5	0.22	5.4	6.5	360 N
Dakhla South	29° 06	24° 37	365	24.5	0.22	5.2	6.4	360 N
Abu Simbel	31° 33	22° 25	198	24.5	0.24	4.5	5.5	360 N

Table 2
Measured and estimated mean wind speed (m/s) for the years 2004–2005 of the selected stations at 24.5 and 10 m height, respectively.

Station	Mean wind speed	Month												Annual mean (m/s)
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	
Kharga	V_{10}	3.9	4.4	5.9	6.0	5.5	5.9	5.9	5.4	6.3	6.2	4.7	4.5	5.4
	$V_{24.5}$	4.7	5.4	7.2	7.3	6.7	7.2	6.8	6.6	7.7	7.6	5.7	5.5	6.5
Dakhla South	V_{10}	4.7	4.4	4.5	4.9	5.3	5.8	5.3	5.3	6.2	6.3	5.0	4.5	5.2
	$V_{24.5}$	5.7	5.4	5.5	6.0	6.4	7.1	6.5	6.4	7.5	7.7	6.1	5.5	6.4
Abu Simbel	V_{10}	3.7	4.4	4.5	5.2	4.8	4.4	4.0	4.3	5.2	4.8	4.6	4.0	4.5
	$V_{24.5}$	4.6	5.4	5.6	6.4	5.9	5.5	4.9	5.3	6.4	6.0	5.7	4.9	5.5

(3) Focus on seasonal variation: wind speeds for all sites undergo noticeable variations with higher values at Spring and Autumn seasons except Dakhla South at Summer and Autumn periods.
(4) This clearly reflects that a wind energy conversion system (WECS) would produce appreciably more energy during Autumn months as compared to the other seasons, e.g. a wind turbine at the three stations would produce during September and October about 2.5 times the energy produced during the months of January and December.
(5) Briefly, the wind speed values are generally high during all seasons except at Winter period for Kharga and Dakhla South stations. On other hand, the lower wind speeds observed at Winter and Summer months for Abu Simbel station, where its wind speed data observed at Spring and Autumn months more slightly higher in the range of 4.8–4.9 m/s at 10 m height.

4. Wind availability analysis

The most important parameter for the calculation of the specific wind energy is the duration for each wind speed separately. The distribution of the wind speed vector of each site is represented by wind rose. This presentation makes it possible to reveal the direction and the intensity of the wind dominant [23]. Fig. 3 represents the analysis of wind speed and direction over the period 2004–2005 for the three stations. One special feature of the wind speed direction at these sites is that it has the same prevailing wind direction "north" throughout the year.

At Kharga station, it is evident from this figure that the wind blows predominantly from N and NNW directions for about 45% followed by 42% from the two sectors, respectively. These winds come with an average wind speed in the range 7.6–7.9 m/s at 24.5 m height. This means that Kharga station has very good winds with long time duration 87% over the two years. So, this site can be explored for installing wind parks. This is in favour of using large size wind generator distributed in rows against these directions, provided there are no high buildings and very large trees and the terrain is smooth in these directions, for optimal energy output.

However, for Dakhla South area, wind direction figure shows that the maximum frequency of occurrence is from the north as illustrated in Fig. 3. Wind from the north sector blows during 54% of the time with an average wind speed of around 7.9 m/s. Also, there were strong winds come from the north-northwest, but their frequencies were moderate 23% of the time with high wind speed around 7.3 m/s during the year. Since most modern wind turbines usually start producing energy above 3.5 m/s, the 77% availability of wind speed the cut-in-speed of wind turbines is a good indication of Dakhla South station being a potential site for wind farm development.

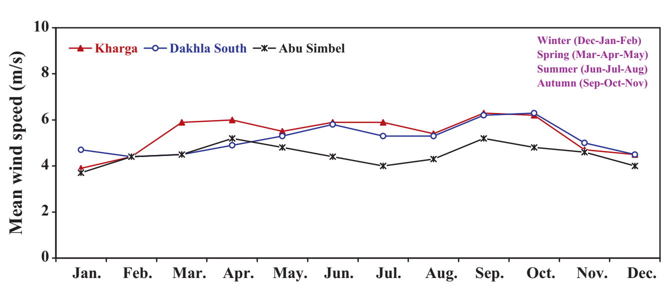

Fig. 2. Monthly average wind speed at 10 m height over two years for the three stations.

Similar from rose diagram of Abu Simbel station: most often the winds are northerly or north-northwesterly as shown in Fig. 3. The duration of these winds are about 40% and 27% of the time. And the level of its wind speed at 24.5 m height is between 7.0 and 6.8 m/s, respectively. Where the most probable wind direction for the 2 years period is 360°, i.e. north winds. Usually the cut-in-speed of wind energy conversion systems is about 3.0 m/s. It is clear from this diagram that wind machines can produce energy around 67% of the times during the entire year at all heights up to 25 m.

Finally, it is worthwhile to remark that: a comparison of the rose diagrams for the years 2004 and 2005 shows that the wind speed is more persistent and blow over this region-deep south Egypt- in two main sectors (N and NNW) with long duration around the range of frequencies from 67% to 87% at the three stations.

5. Standard deviation and coefficient of variation

Shape (k) and scale (c) parameters of the Weibull function were calculated for all sites at 10 m height using the method mentioned in our previous article [9]. The results of the calculation were introduced at Table 3. In general, the noticed variation for the monthly values of k and c is very little at the three stations under study. This means that the atmosphere has a steady state case over them. Also, the dimensionless shape parameter k is not greater than 2.1 during the year. This leads to widely dispersed data, i.e. the data tend to distributed uniformly over a relatively wide range wind of speed. Hence, this is a positive indicator for wind power generation at these regions.

The long-term average wind speed ν and the standard deviation σ, can be calculated as follows [24]:

$$\sigma = \nu k^{-0.921} \quad (1)$$

From the third row in Table 3, the estimated values of standard deviations are summarized and show that the most variable monthly average wind was in the periods from March to October for Kharga station. The standard deviation values tend to be higher during these months. i.e. during all seasons except winter months where the lowest standard deviation is calculated in the month of January as 2.47 m/s. However, for Dakhla South area these high values have been observed only at Summer and Autumn months. On the other hand, the variety of the monthly standard deviation values is in the narrow range during the year at Abu Simbel region.

The coefficient of variation is calculated as a measure of the wind variability and is defined as the percentage ratio of the standard

Table 3
Weibull parameters, standard deviation and coefficients of variation for three sites in South Egypt at 10 m height.

Station	Parameter	Month												Annual mean
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	
Kharga	k	1.64	1.74	2.02	2.03	1.95	2.02	2.02	1.93	2.08	2.07	1.80	1.76	1.92
	c	4.3	4.9	6.7	6.8	6.2	6.7	6.7	6.1	7.1	7.0	5.3	5.1	6.1
	σ	2.47	2.64	3.09	3.13	2.97	3.09	3.09	2.95	3.21	3.17	2.74	2.67	2.94
	VC %	63	60	52	52	54	52	52	54	51	51	58	59	55
Dakhla South	k	1.80	1.74	1.76	1.84	1.91	2.00	1.91	1.91	2.07	2.08	1.86	1.76	1.89
	c	5.3	4.9	5.1	5.5	6.0	6.5	6.0	6.0	7.0	7.1	5.6	5.1	5.8
	σ	2.74	2.64	2.67	2.79	2.92	3.06	2.92	2.92	3.17	3.21	2.82	2.67	2.88
	VC %	58	60	59	57	55	53	55	55	51	51	56	59	56
Abu Simbel	k	1.60	1.74	1.76	1.89	1.82	1.74	1.66	1.72	1.89	1.82	1.78	1.66	1.76
	c	4.1	4.9	5.1	5.9	5.4	4.9	4.5	4.8	5.9	5.4	5.2	4.5	5.1
	σ	2.40	2.64	2.67	2.89	2.77	2.64	2.51	2.61	2.89	2.77	2.70	2.51	2.67
	VC %	65	60	59	56	58	60	63	61	56	58	59	63	60

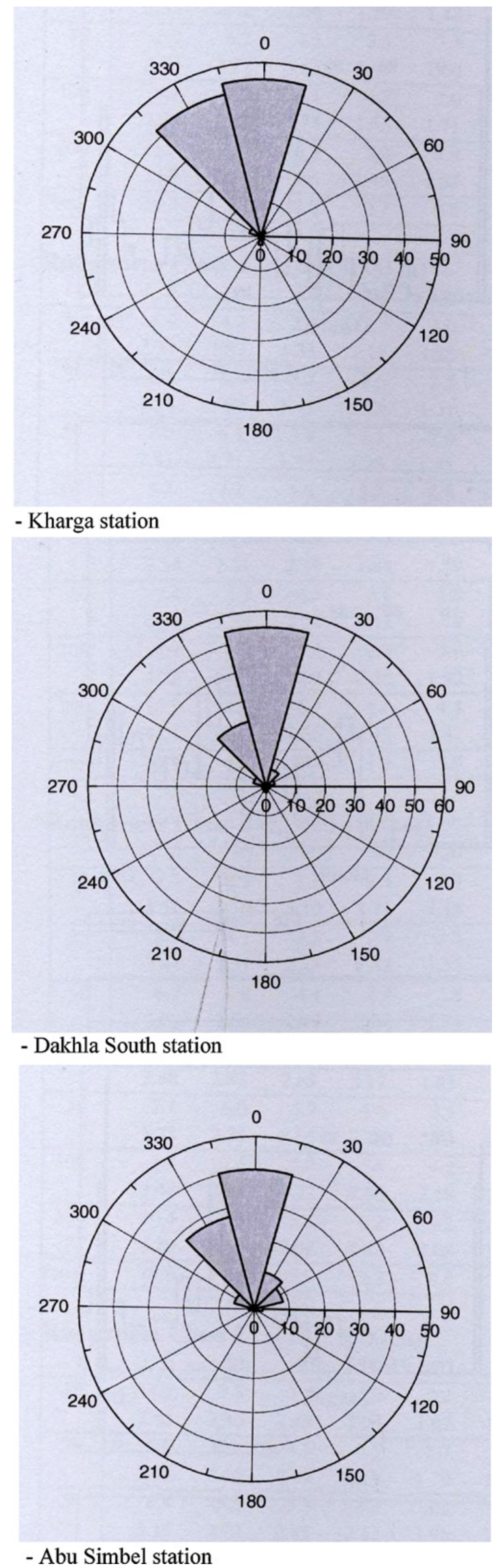

Fig. 3. Diagrams of wind rose for the three locations at 24.5 m height of measured data.

deviation of the annual mean wind speeds from the mean wind speeds [25,26]. These coefficients are presented in the fourth row of Table 3. As it can be read in this table, they range from 51 to 63% with an average value of 55% for Kharga station. In addition, these monthly values between 51 and 60% with an annual mean equal to 56% for Dakhla South station. However, at Abu Simbel area the

monthly coefficient of variation in the range from 56 to 65%, where its annual value is 60%. This means that:

(1) The ratio increases when moving from the northern regions (e.g. Kharga area) towards the southern regions (Abu Simbel area). Where the air pressure and sunshine duration are higher, which in parallel to the noticed decrease of mean wind speeds.
(2) Indeed, the weather is more stability throughout the year at Kharga and Dakhla South regions than Abu Simbel station.

6. The estimation and extrapolation of wind power density

Wind cannot be transported and, therefore, wind turbines must be located where the wind resource is present. The energy content of the wind, being related to the cube of the wind speed, varies significantly with only small changes in wind speed. This fact demands the importance of having accurate wind speed data when the wind energy resource is being evaluated. Since wind speed is a continuously varying parameter, it is customary to average the wind speeds during each hour and to use the hourly mean wind speed as the basic parameter in calculations of wind power.

There are several methods that can be used to estimate available wind power at a site. The first method used here is the one that is based on the assumption that the yearly mean wind speed, v_1 (the means of the sum of the monthly wind speed v) and a perturbation from the mean v_2 has been determined, the actual wind speed is now $v = v_1 + v_2$. The value of v_2 can be expressed as $3v_1\sigma^2$, where σ^2 is the variance of 12 mean monthly wind speed. Then the available wind power, P_σ, can then be calculated from the relation [27,28]:

$$P_\sigma = \frac{1}{2}\rho(v_1^3 + 3v_1\sigma^2) \quad (\mathrm{W/m^2}) \tag{2}$$

This equation for estimating available wind power at a site is considered to be better than the other methods because it takes into consideration the variation in monthly mean wind speed, where ρ is the air density (1.225 kg/m^3) at a given site.

In the second method, the change in the density of air may cause an improvement in the power output of wind turbines, due to relatively less load offered by air [9]. And the air density is an important parameter whereas wind power calculation is concerned. So, our estimate is based on the following idea. Ideal power in the wind calculated as the following:

$$P_\mathrm{w} = \frac{1}{2}\rho v^3 \quad (\mathrm{W/m^2}) \tag{3}$$

Then, due to the measurements of the temperature and pressure data that needed for corrected air density values not available for the stations under this study. A rough estimate of the air density can be obtained by the following discussion. Based on the air density depends on elevation, temperature and pressure. We shall use its value at sea level, at standard pressure of 101.3 kPa and T = 273 K. According to the expression [29,30]:

$$\rho = 3.485\frac{P}{T} \tag{4}$$

i.e. ρ = 1.293 kg/m^3. Thus, the formula (3) for the maximum possible power per unit area theoretically, can be calculated by:

$$P_\mathrm{w} = 0.647v^3 \quad (\mathrm{W/m^2}) \tag{5}$$

For Kharga, Dakhla South and Abu Simbel locations, the two methods were employed to provide practical estimations for monthly wind power available at 10 m height. This calculations were done by using Eqs. (2) and (5). Table 4 gives the mean power densities computed by the two methods. Additionally, in order to provide more data points for comparison Fig. 4 was illustrated.

To confirm the validity of our results, the greatest negative bias [10] between the monthly values of P_σ and P_w were evaluated for

Table 4
Monthly and annual wind power available at 10 height estimated by two different methods beside bias for the three regions.

Station	Wind power density (W/m^2)	Month												Annual mean
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	
Kharga	P_σ	39	55	129	135	105	129	129	99	156	149	67	59	104
	P_w	38	55	133	140	108	133	133	102	162	154	67	59	107
	Bias error	−0.026	0.0	0.031	0.037	0.029	0.031	0.031	0.030	0.038	0.034	0.0	0.0	0.020
Dakhla South	P_σ	67	55	59	75	94	123	94	94	149	156	79	59	92
	P_w	67	55	59	76	96	126	96	96	154	162	81	59	94
	Bias error	0.0	0.0	0.0	0.013	0.021	0.024	0.021	0.021	0.034	0.038	0.025	0.0	0.016
Abu Simbel	P_σ	34	55	59	89	71	55	42	52	89	71	63	42	60
	P_w	33	55	59	91	72	55	41	51	91	72	63	41	60
	Bias error	−0.029	0.0	0.0	0.022	0.014	0.0	−0.024	−0.019	0.022	0.014	0.0	−0.024	−0.002

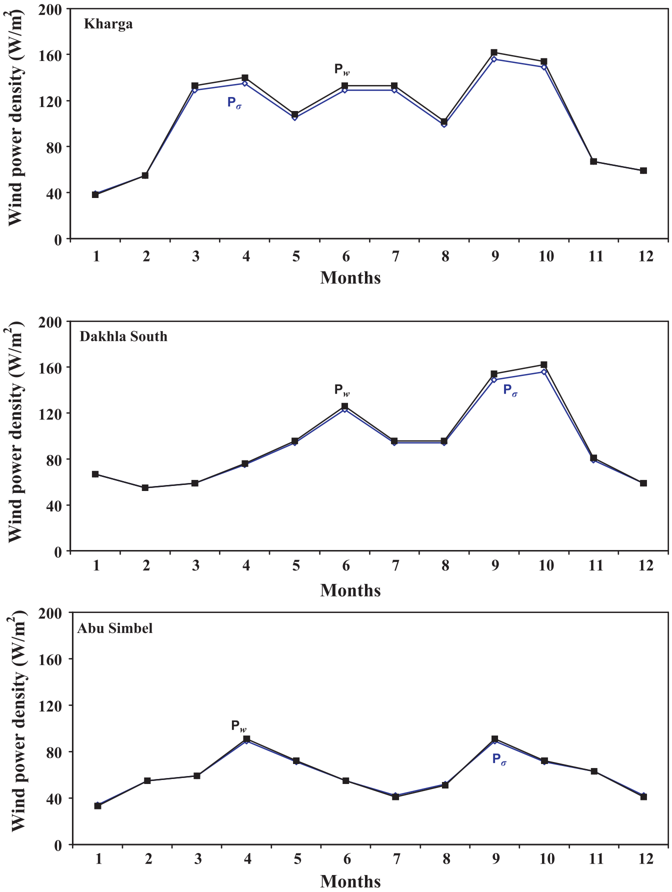

Fig. 4. Variation of monthly wind power computed at 10 m height by using two different methods at three selected stations.

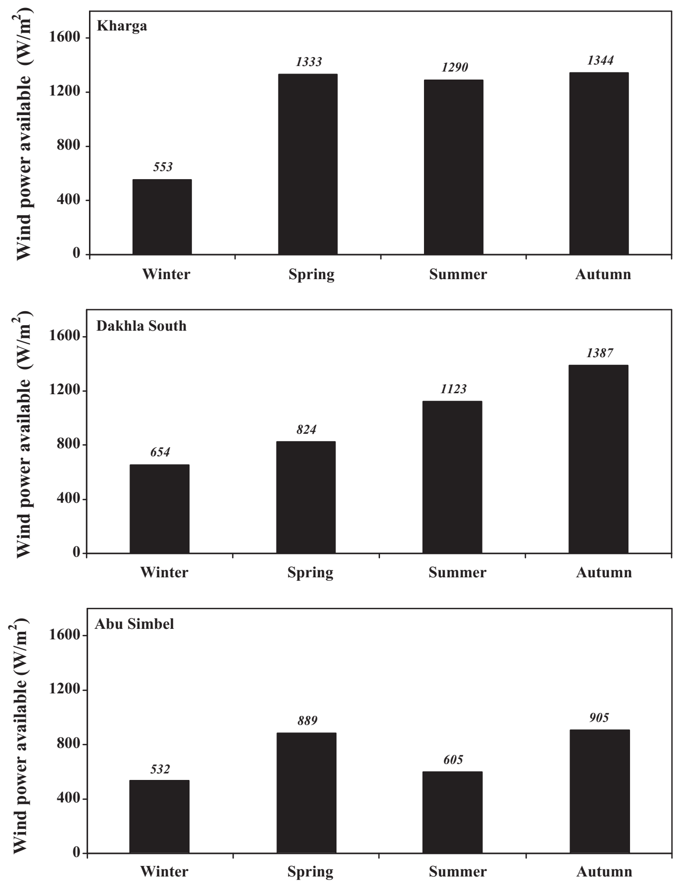

Fig. 5. Expected seasonal averages of wind power density over the year at 70 m hub height for the three regions at South Egypt.

each station and also listed in Table 4. From these table and figure it is clear that:

(1) It is evident that both methods give identical estimates for the expected monthly wind power density available at 10 m height for each site. Where the results for P_σ and P_W agree within 99% according the bias error estimates (see Table 4).
(2) The two peaks of P_σ and P_W for every region which are introduced at Fig. 4 have the same trend and pronounced peaks. But the obtained values by the second method of P_W are very slightly higher than the estimated values of P_σ. So, this very small gab illustrated between them is understanding that confirms the idea that the air density parameter plays an important step to evaluate the correct expected wind power potential for a site.
(3) Although Kharga region, it has still lower elevation above the ground level 102 m compared with another stations under this study. The highest wind power density is available in Kharga area is about 2 times the expected wind potential at Abu Simbel region (see Tables 1 and 4).

Wind resource classification system, developed by US National Renewable Energy Laboratory, is perhaps that the most widely used and designed for a nominal height is 50 m, whereas the standard height for large wind turbines is now 65 m or more. Additionally, the effect of height on air density for the elevations under consideration is negligible, the power density of the wind above the ground level will be mainly affected by the increase in wind speed with height [31–33]. It should be preferred to choose a suitable method from last our discussion in order to make a correct estimation at the desired elevations. Thus, we have chosen the first method. And the vertically extrapolated wind power values to 70 m height for all stations are calculated by using the specific monthly values, P_σ, of available wind power at 10 m height which listed at Table 4 and then by substituting these values in the equation stated in our article [34]. This is done to estimate the seasonal wind density available at 70 m hub height for the three locations. The results were depicted at Fig. 5. It is interesting to note that:

(1) Kharga station has seasonally wind power in the range from 553 to 1344 W/m^2. Where the expected wind power density is high over the year with exception Winter months. Again, this area possesses a huge annual mean wind power 377 W/m^2 at a height 70 m above ground level. This result is similar to the power density in some European countries [33].
(2) The seasonal power density obtained from the wind at Dakhla South region is ranging from 654 to 1387 W/m^2. Indeed, wind powers increase in value when moving from Winter months towards Autumn season during the year. Where the richness of wind density was at Autumn period. Additionally, the wind power density at 70 m height of it is found to be 333 W/m^2 annually.
(3) Hence, Kharga and Dakhla South locations are ideal for electricity generation because they have already annual mean wind speeds between 5.2 and 6.5 m/s (at the heights 10 and 24.5 m, see Table 1) and possess power density is nearby the inland wind potential of Vindeby (Denmark). So, these regions in South Egypt are appropriate for the application of large wind turbines with a capacity up to 1000 kW or more for electricity generation.

(4) However, Abu Simbel station has a low relatively wind power available during the whole year with annual mean wind power density for about 244 W/m^2. Due to these relatively moderate wind powers available at 70 m hub height, practically it can be used eventually and profitably for local and small applications. Therefore, the best application of wind energy for this area is installation of medium size WEC systems (600–750 kW).

7. Conclusions and recommendations

It is quite evident from the present preliminary study that the potential of wind energy can not be overlooked at Deep South Egypt. As seen from the results of the present of analysis, we conclude that:

(1) The wind shear coefficients were calculated using precise measurements of wind speeds for the three sites. These obtained coefficients should be used to calculate the wind speed at different hub heights if wind measurements are available at one height for all locations under this study. Kharga station has a velocity of higher than 5.4 m/s at 10 m height for eight months in the year compared with Dakhla South area which has wind speeds of 5 m/s and higher for seven months. Otherwise, Abu Simbel region possesses only a velocity of 5.2 m/s for two months.

(2) Focus on seasonal variation: wind speeds for all sites undergo higher values at Spring and Autumn seasons except Dakhla South region at Summer and Autumn periods. Thus, the Autumn months provide the major portion of the wind energy at the three stations with high wind potential. One special feature of the wind speed direction at these sites is that it has the same prevailing wind direction "north" throughout the year.

(3) According to wind availability analysis: Kharga area has very good winds with long time duration 87% from N and NNW directions over the two years with an average wind speed in the range 7.6–7.9 m/s at 24.5 m height. Similar, for Dakhla South region, their wind speeds blow in two main sectors 360° and 330° with long duration of frequencies 77% with an average wind speed between 7.3 and 7.9 m/s. These locations are very convenient for wind turbine installations where their suitability and availability for these applications are acceptable in terms of other aspects. As well, Abu Simbel region: most often their winds also are northerly or north-northwesterly. The duration of these winds are about 40% and 27% of the time. And the level of its wind speed was from 7.0 to 6.8 m/s, respectively. It is clear that wind machines at this region can produce energy around 67% of the times during the entire year at all heights up to 25 m.

(4) In general of Weibull parameters, the noticed variation for the estimated monthly values of k and c is very little at the three sites. This observation means that the atmosphere has a steady state case over them. Also, the parameter k is not greater than 2.1 during the year. This leads to widely dispersed wind data, which is a positive indicator for wind power generation at these regions. As it can be read from the obtained values of the coefficient of variation in the fourth row of Table 3 that: the ratio increases when moving from the northern regions (e.g. Kharga area) towards the southern regions (Abu Simbel area). Indeed, the weather is more stability throughout the year at Kharga and Dakhla South regions than Abu Simbel station.

(5) It is evident that both methods applied at this study gives identical estimates for the expected monthly wind power density available at 10 m height for each site. Where the results for P_σ and P_w agree within 99% according the bias error estimates and the two peaks of them for every site have the same trend and pronounced peaks that confirm the validity of our results. The important point derived from this research that: the highest wind power density is available in Kharga station is about 2 times the expected wind potential at Abu Simbel region, although Kharga region, it has still lower elevation above the ground level 102 m compared with another stations.

(6) Investigation of available wind power density at 70 m hub height indicates that: Kharga area has seasonally wind power in the range from 553 to 1344 W/m^2. Again, this area possesses a huge annual mean wind power 377 W/m^2. While, for Dakhla South region seasonally wind powers increase in value over the year when moving from Winter months towards Autumn season with an average of 333 W/m^2 annually. However, Abu Simbel location has a low relatively wind power available with annual mean wind power density for about 244 W/m^2. Due to these relatively moderate wind powers available at 70 m hub height, practically it can be used eventually and profitably for local and small applications. Hence, the best application of wind energy for Abu Simbel area is installation of wind turbines medium size (600–750 kW) can be implemented to supply the city with electricity and for water pumping, where there are small communities living at Abu Simbel region.

(7) In view of the encouraging results of this study for the feature of wind energy utilization in Deep South Egypt: Kharga and Dakhla South locations are ideal for electricity generation because they have already annual mean wind speeds between 5.2 and 6.5 m/s (at the heights 10 and 24.5 m) and possess power density similar to the power density in some European countries, which is nearby the inland wind potential of Vindeby (Denmark). So, these regions are suitable for the plantation wind energy turbines each having at least 1000 kW or more. There are very large areas to construct wind parks. It is not only convenient for wind turbine farms as a landscape but also it is very efficient in terms of wind speed.

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